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Cooled and Uncooled Varactors for Paramp Applications

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LINCOLN LABORATORY

COOLED AND UNCOOLED VARACTORS FOR PARAMP APPLICATIONS

F. J. DOMINICK

Group 46

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Abstract

A discussion of the properties needed to obtain high-quality varactors is presented. Test data are also presented on state-of-the-art varactors as they are cooled from room temperature ($290^{\circ}K$) to liquid helium temperature ($4.2^{\circ}K$).

Accepted for the Air Force
Franklin C. Hudson
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A varactor is a back-biased semiconductor diode that, because of its non-linear properties, is used as the active element in (1) parametric amplifiers, (2) harmonic generators (for solid-state pump sources) and (3) for limiters, switches and phase shifters. For all applications mentioned above, a variation in capacity is required but the use of this variation is different in all cases. This discussion will consider only the varactor as used in parametric amplifiers.

The parametric amplifier requires the varactor to have a significant non-linearity in capacitance for a small amount of pump power with little or no loss.

In fabricating varactors with these requirements consideration must be given to the following: (1) materials, (2) structures, (3) contacts, and (4) junctions.

Materials In order to select the optimum semiconductor material from which to construct the highest cutoff frequency varactors, we can formulate the expression for the cutoff frequency in terms of the bulk physical properties of the material.

$$\text{The cutoff frequency, } f_c = \frac{1}{2\pi R_s C_j} \quad (1)$$

where R_s = series resistance

C_j = junction capacitance.

Consider a cylindrical mesa structure of small area with an abrupt junction. The series resistance may than be expressed as:[1]

$$R_s = \frac{\rho L}{A} + \frac{\rho}{2d} \quad (2)$$

where ρ = resistivity of the base material,

L = mesa height or thickness,

A = area of the junction,

d = diameter of the junction.

Since $\rho = \frac{1}{q\mu N}$ (3)

where q = electronic charge (1.6×10^{-19} coulomb)

μ = majority carrier mobility (cm^2/volt-sec)

N = ionized impurity concentration (carriers/cc)

The series resistance is

$$R_s = \frac{1}{q\mu N} \left[\frac{L}{A} + \frac{1}{2d}\right] . \tag{4}$$

The capacitance as a function of voltage for an abrupt junction may be written as:(1)

$$C_j = \frac{A\epsilon}{\sqrt{\frac{2\epsilon V_o}{qN}}} \tag{5}$$

where ϵ = dielectric constant

$V_o = \Psi - V_{(applied)}$

Ψ = contact or built-in potential.

Substituting Eqs. (4) and (5) into Eq. (1) we obtain, assuming no applied voltage:

$$f_c = \frac{\mu\sqrt{\frac{2qN}{\epsilon}\Psi}}{2\pi\left(L + \frac{A}{2d}\right)} = \frac{\mu\sqrt{\frac{2qN}{\epsilon}\Psi}}{2\pi\left(L + \frac{\pi d}{8}\right)} \tag{6}$$

Since the impurity concentration N, charge q, and the geometrical properties L and d are independent of the type of material used, a material figure of merit may be defined as equal to:

$$M = \mu\sqrt{\frac{\Psi}{\epsilon}} \tag{7}$$

A large material figure of merit will result in a varactor with a large f_c.

Table 1 contains the properties of the most promising semiconductor materials.

TABLE 1

Material	μ (cm^2/volt-sec)	φ (volts)	ϵ	M
Si	1,500	0.7	11.8	3.9×10^2
Ge	3,900	0.5	16.0	6.9×10^2
GaAs	5,000	1.0	11.1	15.0×10^2
InAs	30,000	0.25	11.7	29.2×10^2
InSb	100,000	0.15	15.9	97.3×10^2

It may be noted from Table 1 that the most promising semiconductor material is InSb (indium antimonide). However, since the energy-gap voltage of InSb is very low (0.18 ev at 290°K), carriers are thermally generated. To reduce these carriers to a convenient useful level, the material must be cooled to below 100°K. A number of varactors fabricated from InSb were obtained from Micro State. Test results obtained at 77°K indicated cutoff frequencies of approximately 1000 GHz. The problem encountered with these varactors, however, was that they would degrade with time. This same degradation with time was observed with InSb varactors obtained from Airborne Instrument Laboratories.

The next promising material indicated in Table 1 is InAs (indium arsenide). This material, however, is very brittle and difficult to handle.

Since GaAs (gallium arsenide) technology has advanced in the past two or three years, varactor manufacturers are fabricating higher-quality GaAs varactors since they have been supplied with higher-quality material. An advantage GaAs has over Si and Ge is that it functions at cryogenic temperatures.

Structures To achieve high-quality varactors would entail lowering the series resistance R_s which is proportional to the resistivity of the semiconductor material (Eq. 1). Data published by H. Kressel, et al.,[2] shows that lowering the resistivity of the material would decrease the breakdown voltage of the varactor. Therefore, some compromise must be made. According to Eq. 2, the series resistance is directly proportional to the mesa height or thickness L. Therefore, providing a minimum amount of semiconductor material in the structure could compensate for the higher resistivity material needed to achieve reasonable breakdown voltages. The different approaches that may be taken to obtain a minimum amount of material are: (1) ultra-thin wafers, (2) dimple diodes, and (3) epitaxial layers. Since the technology of forming epitaxial GaAs layers has advanced rapidly, it is now possible to obtain layers with thicknesses of 1 micron. The difficulty to fabricate structures with thicknesses of 1 micron would exclude the other approaches mentioned above.

An epitaxial structure is formed by evaporating a layer of high-resistivity n- or p-type material on a highly degenerate substrate (highly doped n- or p-type material). The evaporation of this layer results in good controllability of the desired material thickness. Fabrication of varactors using this epitaxial technique results in a better yield of devices from a slice of material since there is a more uniform impurity distribution. Prior to the development of the epitaxial technique, varactors were fabricated using the ultra-thin wafer or as it is known, the nonepitaxial technique. This technique uses very thin wafers sliced from a raw ingot which has been oriented in the proper axis. This raw ingot is a crystal that has been grown in a crystal pulling furnace. Since these wafers cannot approach the desired 1 micron thickness, cutoff frequencies greater than 200 GHz cannot be achieved.

Contacts The typical contacts used by varactor manufacturers have been C-springs, diaphragms and bonded leads. This contact resistance is typically 0.1 Ω. The contact nearer the junction (p-type contact for a diffused n-type GaAs structure) should be etch resistant and should serve to define the active junction area. For C_j, equal to 0.5 pf, as is needed at X-band, a contact

diameter of 1 mil is required. To attain continuity between the contact and the package, the contact must have a suitable surface and protrude above the semiconductor wafer. Since epitaxial layer thicknesses of 1 micron are desired and diffusion depths of 0.25 to 0.50 micron are used, care must be taken not to penetrate the semiconductor surface but firmly adhere to it. For p-n junctions a tin-nickel combination may be used as the contact for the highly degenerate substrate. Rh-plated gold mesh or wire 0.3 mil thick may be bonded to the p-type side.

Junctions The type of junction preferred in varactors for low-noise paramp applications is one in which the capacitance variation with voltage is rapid. For a varactor the capacitance variation with voltage is given as:[3]

$$C_j(V) = C_{j_o}\left(1 - \frac{V}{\varphi}\right)^{-\frac{1}{n}} \tag{8}$$

$$\frac{dC_j(V)}{dV} = \frac{C_{j_o}}{n\varphi}\left(1 - \frac{V}{\varphi}\right)^{-\frac{1}{n} - 1} \tag{9}$$

$$= \frac{C_j(V)}{n\varphi}\left[\frac{1}{1 - \frac{V}{\varphi}}\right]$$

$$\therefore \frac{dC_j(V)}{C_j(V)} = \frac{1}{n(\varphi - V)}\, dV \tag{10}$$

where φ = contact potential

n = 1, 2 and 3

when n = 3, we have a graded junction

= 2, we have a step or abrupt junction

= 1, we have a hyper-abrupt junction (which is difficult to fabricate).

Two types of junctions currently being used by varactor manufacturers are (1) diffused, and (2), Schottky[4] barrier (also known as surface barrier and hot carrier). A diffused p-n junction is formed in an evacuated quartz ampoule into which a slice of n-type GaAs, zinc pellets and crushed GaAs is placed (see Fig. 1). This entire assembly is then placed into a temperature-controlled oven. At the appropriate temperature and time the zinc will diffuse into the GaAs to the desired depth (see Fig. 2). The crushed GaAs provides the necessary arsenic vapor pressure in the ampoule. The zinc diffused slice is then removed from the ampoule and is diced, polished and contacts are placed on the p and n side of the sample. This sample is then etched to obtain the desired junction (see Fig. 2a) area. Using the above-mentioned diffusion technique, diffusion depths of less than 2 microns are difficult to achieve. A technique used by B.T.L. has proven to be quite feasible and has made it possible to achieve 0.2 to 0.5 micron diffusion depths in an epitaxial layer thickness of 1 micron. It may be in order to mention that the diffusion depth should not be less than the width of the space charge region; for example, a varactor with a breakdown voltage of 6 volts has a space charge region width of 0.1 micron. Diffused junctions exhibit a capacitance variation that varies inversely between n = 2 and 3 with voltage.

A Schottky barrier diode, also known as a surface barrier or a hot carrier diode, has a metal-semiconductor junction (see Fig. 3). Schottky developed a simple theory for the formation of a surface barrier at a metal semiconductor contact. This theory was further developed by Schottky[5] when Mott[6] suggested that the mechanism of current flow in barrier layer diodes was by thermal excitation of carriers over the surface barrier. Figure 4 shows an energy level diagram of a Schottky barrier diode. When the diode is biased in the forward direction (Fig. 4a), the electrons in the n-type semiconductor diffuse over the barrier and are injected into the metal. These electrons have an energy higher than that of the free electrons existing in the metal. Therefore, the name "hot carrier" was coined. In this forward biased condition there is no flow of minority carriers in the reverse direction; therefore, the response to a sudden change in bias is much faster than in p-n junctions. The capacitance

of a Schottky barrier device varies as the inverse square root of the voltage which is ideal for paramp applications.

The details of the preparation of the crystals and fabrication of the Schottky barrier varactors have appeared in an article by C. J. Frosch.[7]

Data on State-of-the-Art Varactors At present the highest reported cutoff frequency obtained in a diffused GaAs varactor was 500 GHz at a bias of zero volts. This varactor was fabricated by Bell Telephone Laboratory in Murray Hill, New Jersey. Cutoff frequencies at 6-volts bias between 300 and 400 GHz have been fabricated by Sylvania and between 400 and 500 GHz by Micro Optics. The lowest noise temperature paramp (uncooled) using varactors supplied by Micro Optics was reported by J. Honda (private communication) of Hughes Aircraft (Los Angeles, California). The noise temperature obtained was $120^{\circ}K$ ($15^{\circ}K$ was due to the second stage) at a signal frequency of 7.8 GHz and a pump frequency of 36 GHz.

Cutoff frequencies of 800 GHz at zero volts bias have been obtained in surface barrier varactors. These devices were fabricated by Bell Telephone Laboratory. Texas Instruments has marketed surface barrier varactors with zero bias cutoff frequencies of 500 GHz. At the Electron Device Meeting held in Washington, D. C. in October, 1965, it was reported by Texas Instruments that these devices were incorporated into a K_u-band (16.5 GHz) paramp. A noise temperature of $200^{\circ}K$ was obtained with a pumping requirement of only 10 mw.

To advance the state of the art of varactors into the millimeter wavelength region of the spectrum, a new configuration called the planar annular varactor was proposed by Autonetics (a subsidiary of North American Aviation, Anaheim, California). The fabrication technique used and test results were presented at the Electron Device Meeting in Washington, D. C. in October, 1964.[8]

The basis for this type of device was conceived from the fact that the skin depth of GaAs decreases as the frequency increases (see Fig. 5). If the thickness of a semiconductor device remains constant and the frequency is

increased, the conduction, which normally is directly through the semiconductor to the base, is confined to the surface of the semiconductor due to the skin effect. This increases the conduction path through the semiconductor to the base which accounts for the increase in loss. The development of the planar annular varactor by Autonetics reduces these losses due to the skin effect and made it possible to achieve zero-volt cutoff frequencies of 1500 GHz. The capacitance of this device varies inversely between n = 2 and n = 3 with voltage and is a function of the diffusion process.

Table 2 lists the best realizable noise temperatures of uncooled paramps at signal frequencies of 8, 16, and 35 GHz utilizing the various varactors previously discussed.

TABLE 2

f_s(GHz)	f_c(GHz)	f_p(GHz)	T_e(optimum)$^{\circ}$K
8	400 @ -6 v	31.5	200
"	500 @ -6 v	41.5	143
"	800 @ 0 v	90.0	50
"	1500 @ 0 v	200	24
16	400 @ -6 v	34.0	500
"	500 @ -6 v	44.0	340
"	800 @ 0 v	100	110
"	1500 @ 0 v	200	50
35	400 @ -6 v	46.3	1800
"	500 @ -6 v	85.0	1100
"	800 @ 0 v	105	280
"	1500 @ 0 v	220	110

Note: The best realizable noise temperature of a mixer at 35 GHz is 3300°K.

The calculations were made utilizing equations in Ref. 9 with the operating bias chosen to be -2 volts with a pumping coefficient of 0.125 (which is pessimistic).

Measurement of Diode Properties Since the quality of varactors is improving, the conventional methods of measuring [10-12] the cutoff frequency must be modified. In these methods a transmission line is terminated by a varactor in an appropriate holder and the cutoff frequency is calculated from VSWR measurements made at various bias voltages. However, holder and transmission-line losses introduce errors into the measurement and must be compensated for. A method[13] which utilizes a transmission type of measurement of a two-port microwave network containing the varactor as the principle component was used to obtain the data reported. A cutaway view of the varactor test fixture is shown in Fig. 6. Since line losses do not affect the precision of the measurement, this device (Fig. 7) is useful in measuring varactor characteristics at cryogenic temperatures. The precision with which R_d (the diode resistance) can be measured depends on how precisely C_j is known. The tolerance for the measurement of R_d is approximately 2 percent for values of R_d near 3 ohms and 6 percent for values of R_d near 1 ohm. The tolerance of the R_d measurement degrades in proportion to the tolerance of C_j.

The noise in paramps is due primarily to the thermal noise generated in the varactor and can be reduced by cooling. This stimulated system engineers to cryogenically cool the paramps to achieve low system noise temperatures. However, circuit designers have been plagued with the problem of obtaining information regarding the quality of varactors as they are cooled. To obtain this information a program was initiated to measure the quality of varactors at cryogenic temperatures and their degradation if any with temperature. Initially, measurements were made at 290°K, 77°K and 4.2°K with very little information available between 77°K and 4.2°K. Results from measurements obtained at these temperatures indicated that the resistance increased appreciably when the varactor was cooled to 4.2°K and increased slightly at 77°K. To obtain information between 77°K and 4.2°K, a method was needed to vary the temperature

between the above-indicated temperatures and control it to $\pm$ 1°K for an appreciable length of time to perform the measurement.

Basically, there are three methods of controlling the cryogenic temperature: (1) the heater method,[14] (2) the vapor pressure method,[15] (3) the helium desorption method.[16]

In the heater method a nichrome heater coil is wrapped around the device. To raise the temperature to the desired level, a current is passed through the coil. This method can provide an accurate temperature control over a small range of temperature near 4.2°K, however, by passing current through the coil adds heat into the dewar and therefore increases its boil-off rate.

The vapor pressure method utilizes a complex mechanical pressure valve in conjunction with a mechanical vacuum pump to regulate the vapor pressure in the inner dewar. Accurate temperature control can be obtained over a very narrow temperature range near 4.2°K.

In the helium desorption method a small amount (30 grams) of activated charcoal (6 to 14 mesh) is placed in the bottom of a helium dewar. The charcoal reduces the warmup rate, at a point in the dewar, from 60°K per hour (if the helium is allowed to boil off) to 10°K per hour, allowing sufficient time to perform measurements. However, this method does not provide for any temperature controllability and re-establishment of previously achieved lower temperature.

An article by R. T. Swim[17] revealed that a useful temperature distribution existed in a helium-nitrogen dewar (Fig. 8). It may be noted from Fig. 8 that the temperature distribution is linear in the region between the fluid levels and also above the higher fluid (nitrogen) level but with different slopes. The break between the two segments always occurs at the surface of the liquid nitrogen at a temperature of approximately 8°K. If the distance between the levels is changed, only the slope of the curve in the lower region changes since in the upper region the temperature at the end point is fixed. The radial temperature distribution in the inner dewar shows a slight increase in temperature near the walls of the dewar. Since both the helium and nitrogen levels decrease with time due to evaporation, the temperature at a point in the

dewar increases with time. In general, the temperature will increase at rates ranging from 10 to 50°K per hour depending on the heat leak and the fluid levels.

The discovery that the temperature distribution inside the helium dewar is a well-behaved function of the height above the fluid prompted the proposal of a new type of temperature control system.

Experimental attempts to vary the temperature of the varactor test fixture manually proved the feasibility of this system. However, this system would require a positional servo system that would seek out the required height to provide the appropriate temperature in the varactor test fixture and would track this temperature as the fluid height changed with time. The task of designing, constructing and evaluating this automatic temperature control system was undertaken by a graduate student at the University of Maine, who, with permission from his thesis advisor, chose this topic for his thesis.[18] A block diagram of the basic system used is shown in Fig. 9. Figures 10 and 11 show the final system used in the evaluation of the varactors at cryogenic temperatures. The evaluation of this automatic temperature control system indicated control capability from 4.2°K to 200°K of approximately 0.125°K.

Using the above-mentioned measuring technique[13] and cryogenic temperature control system, a number of varactors were measured. During these measurements, the varactor capacitance, which decreases with temperature, is kept at a constant value by varying the bias voltage on the varactor. The results of these measurements are presented in Figs. 12 through 16.

It may be concluded from the results presented in Table 2 and from Figs. 12 through 16 that for uncooled and cooled paramps the surface barrier varactor has the greatest potential. The results also indicate that for a diffused epitaxial GaAs varactor the resistance at 20°K is less than at 4.2°K. These varactors, when operated in a paramp, would contribute less noise when cooled to 20°K than when cooled to 4.2°K. One should not, however, disregard the planar annular varactor especially for high-frequency applications where it has much merit.

REFERENCES

1. Joseph Lindmayer, Charles Y. Wrigley, Fundamentals of Semiconductor Devices, (Van Nostrand Series, 1965).
2. H. Kressel, A. Blicher, L. Gibbons, "Breakdown Voltage of GaAs Diodes Having Nearly Abrupt Junction," Proc. of IRE 50, No. 12, 2493 (December 1962).
3. P. Penfield, R. Rafuse, Varactor Applications, (M.I.T. Press, Cambridge Mass., 1962) p. 57-91.
4. W. Schottky, Z. Physik 113, 367 (1939).
5. W. Schottky, Z. Physik 118, 539 (1942).
6. N. R. Mott, Proc. Roy. Soc. London A171, 27 (1939).
7. C. J. Frosch and L. Derick, J. Electrochem. Soc. 108, 251 (1961).
8. D. B. Anderson, et al., "The Planar Annular Varactor and Its Application to Millimeter Wave Parametric Transducers," Electron Device Conference, October 1964.
9. C. R. Boyd, Jr., "Design Considerations for Parametric Amplifier Low-Noise Performance," IRE Trans. on Military Electronics (April 1961) p. 76-77.
10. N. Houlding, "Measurement of Varactor Quality," Microwave Journal, (January 1960) p. 40-45.
11. R. T. Harrison, "Parametric Diode Q Measurements," Microwave Journal, (May 1960) p. 43-46.
12. K. Kurokawa, "Use of Passive Circuit Measurements for Adjustments of Variable Capacitance Amplifiers," Bell Telephone Systems Technical Publications, Monograph 4089.
13. C. Blake, F. J. Dominick, "Transmission Test Method for High-Q Varactors," MicroWaves (January 1965) p. 18-23.
14. C. Blake, C. E. Chase, Rev. Sci. Inst. (September 1963).
15. H. S. Sommes, Rev. Sci. Inst. (August 1957).
16. P. D. Gianino, "Drastic Reduction of Warm-up Rate Within a Dewar System by Helium Desorption," Physical Sciences Research Paper No. 9, AFCRL.
17. R. T. Swim, "Temperature Distribution in Liquid and Vapor Phases of Helium in Cylindrical Dewars," Advances in Cryogenic Engineering Vol. 5, 498 (Plenum Press, Inc., N. Y., 1960).
18. K. Bach, "An Investigation of Temperature Control for Microwave Measurements at Cryogenic Temperatures," thesis for M.S. in E.E., University of Maine (August 1965).

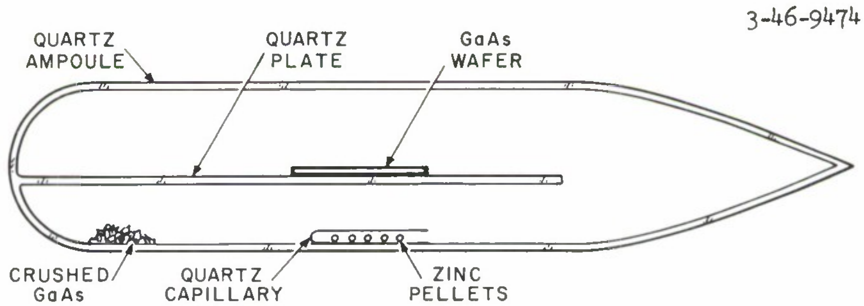

Fig. 1 Sealed diffusion ampoule.

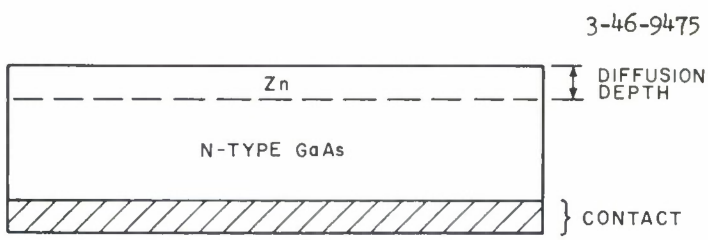

Fig. 2 A zinc diffused GaAs slice.

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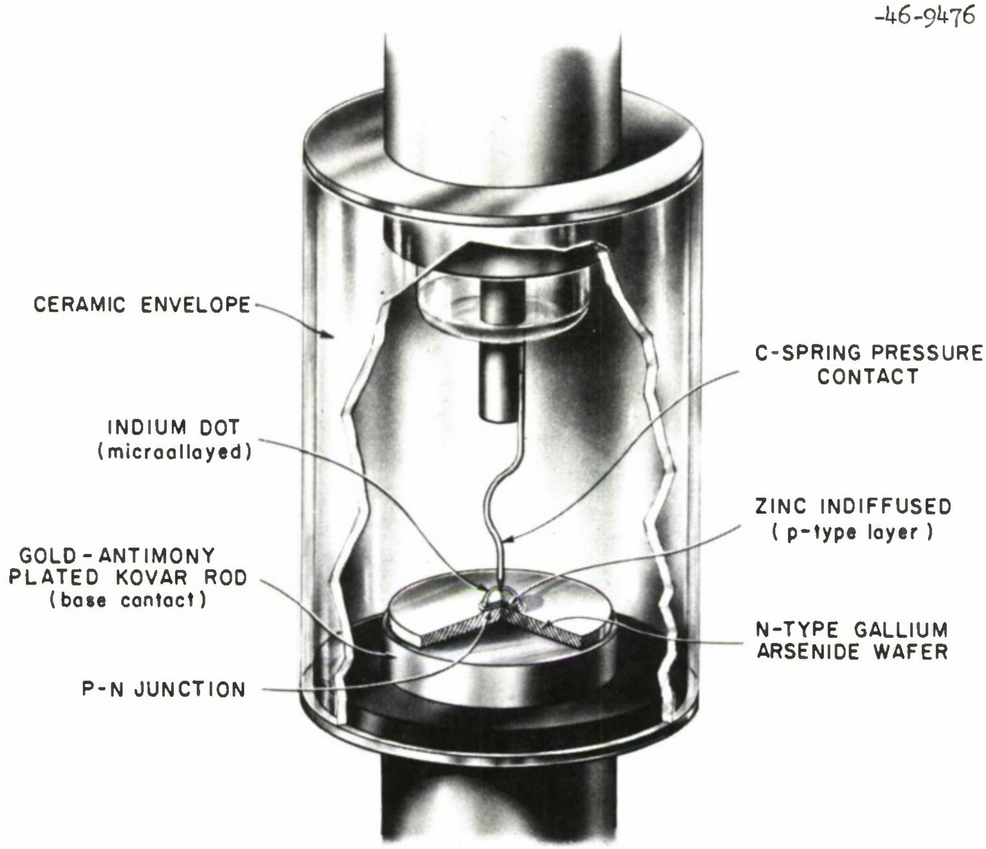

Fig. 2a A cutaway view of a typical varactor.

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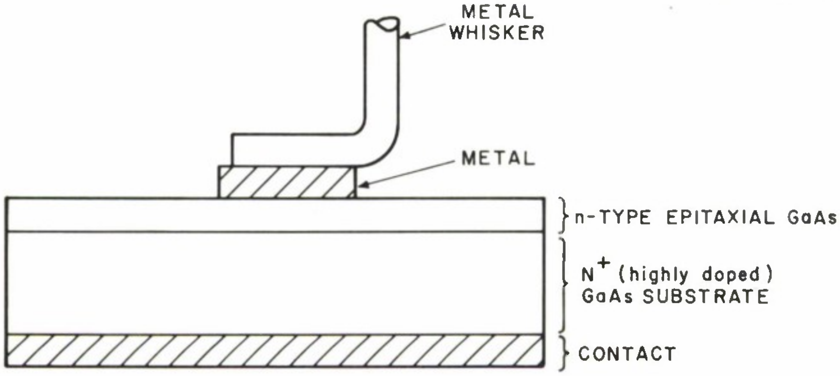

Fig. 3 A Schottky barrier junction.

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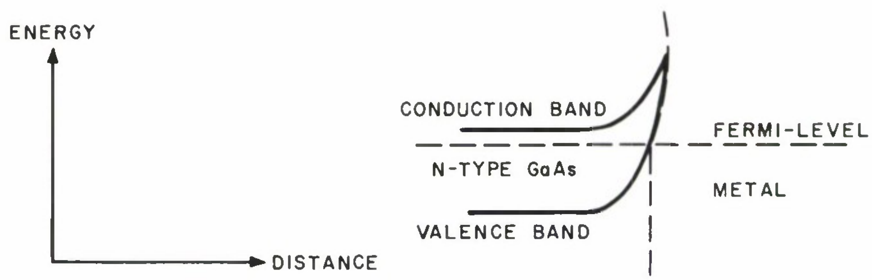

Fig. 4 Energy level diagram of a Schottky barrier varactor.

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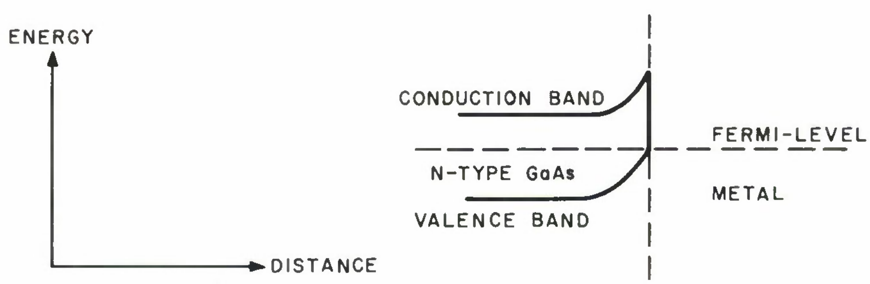

Fig. 4a Energy level diagram of a Schottky barrier varactor forward biased.

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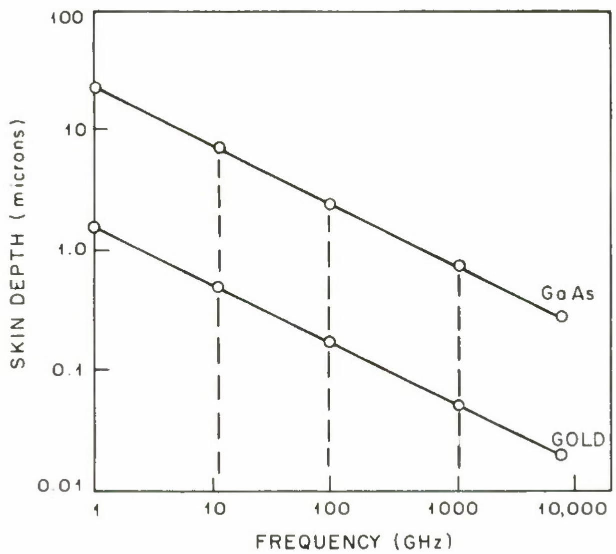

Fig. 5 Skin depth of GaAs versus frequency.

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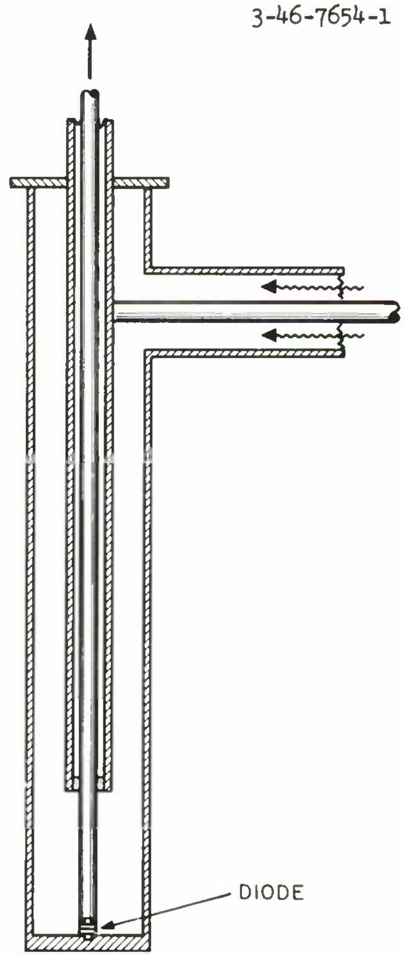

Fig. 6 A cutaway view of the varactor test fixture.

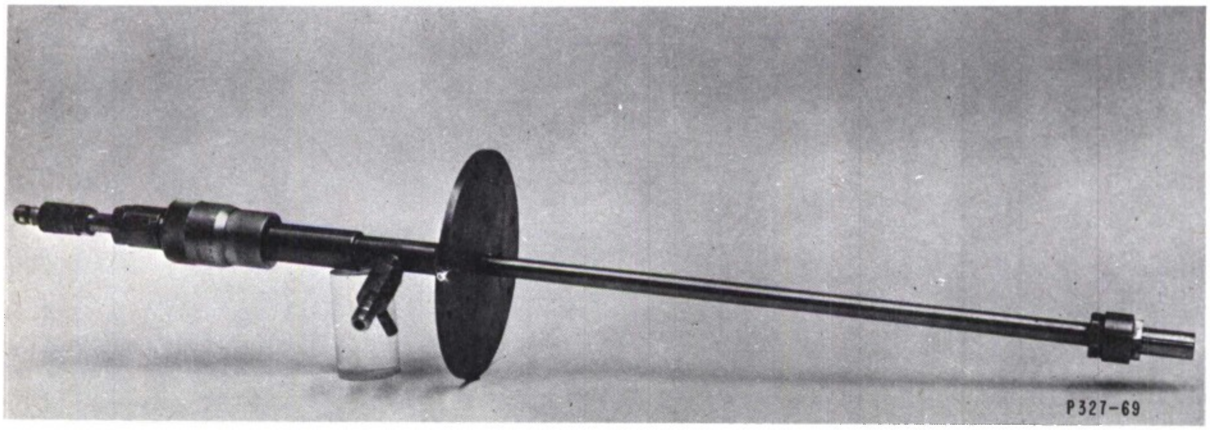

Fig. 7 A photograph of the varactor test fixture.

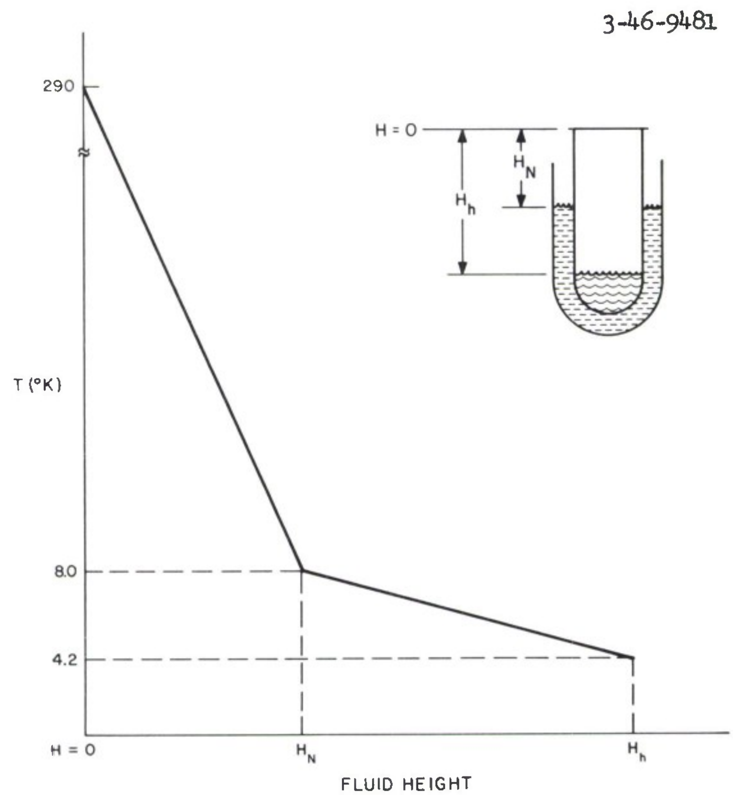

Fig. 8 Temperature distribution in a helium-nitrogen dewar.

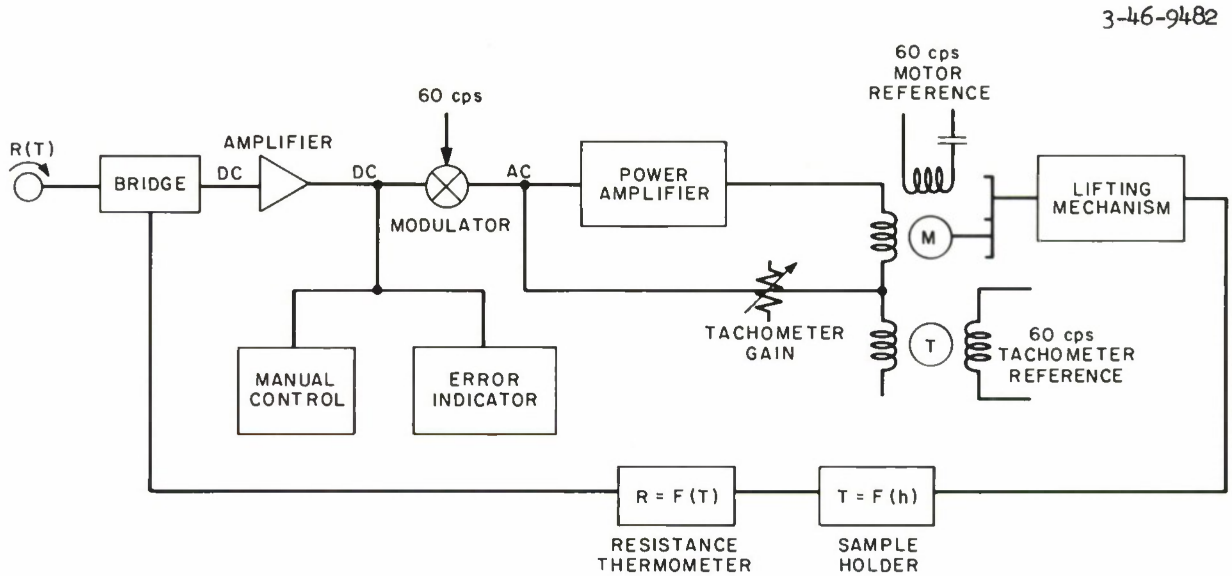

Fig. 9 Basic system for cryogenic temperature control.

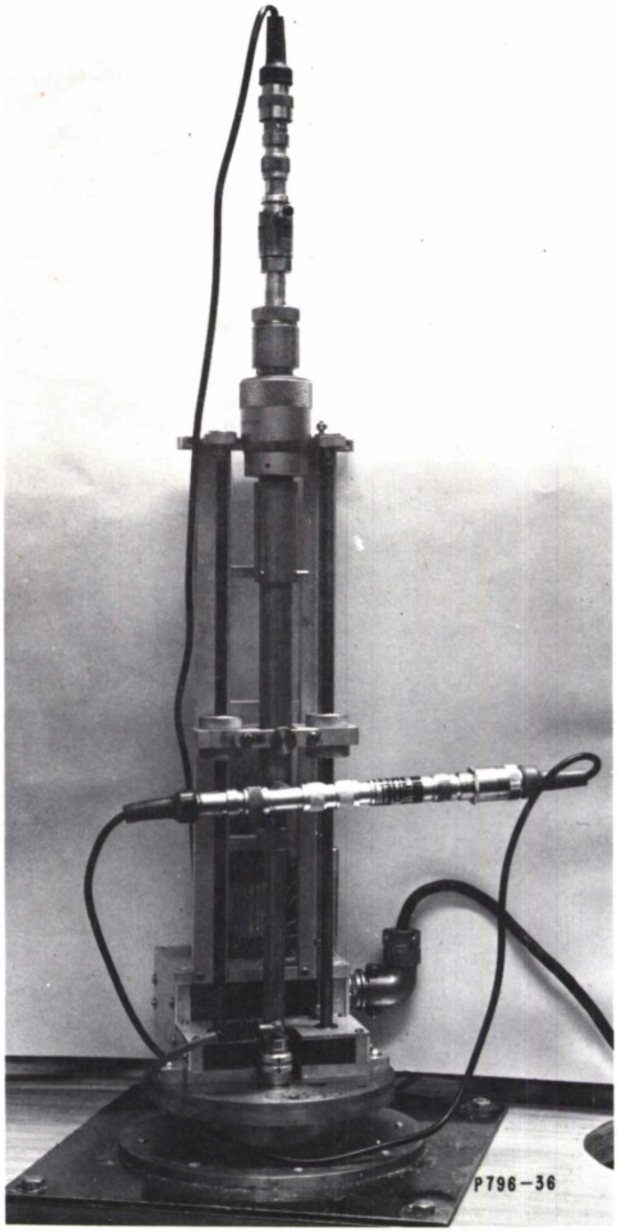

Fig. 10 Mechanical drive mechanism.

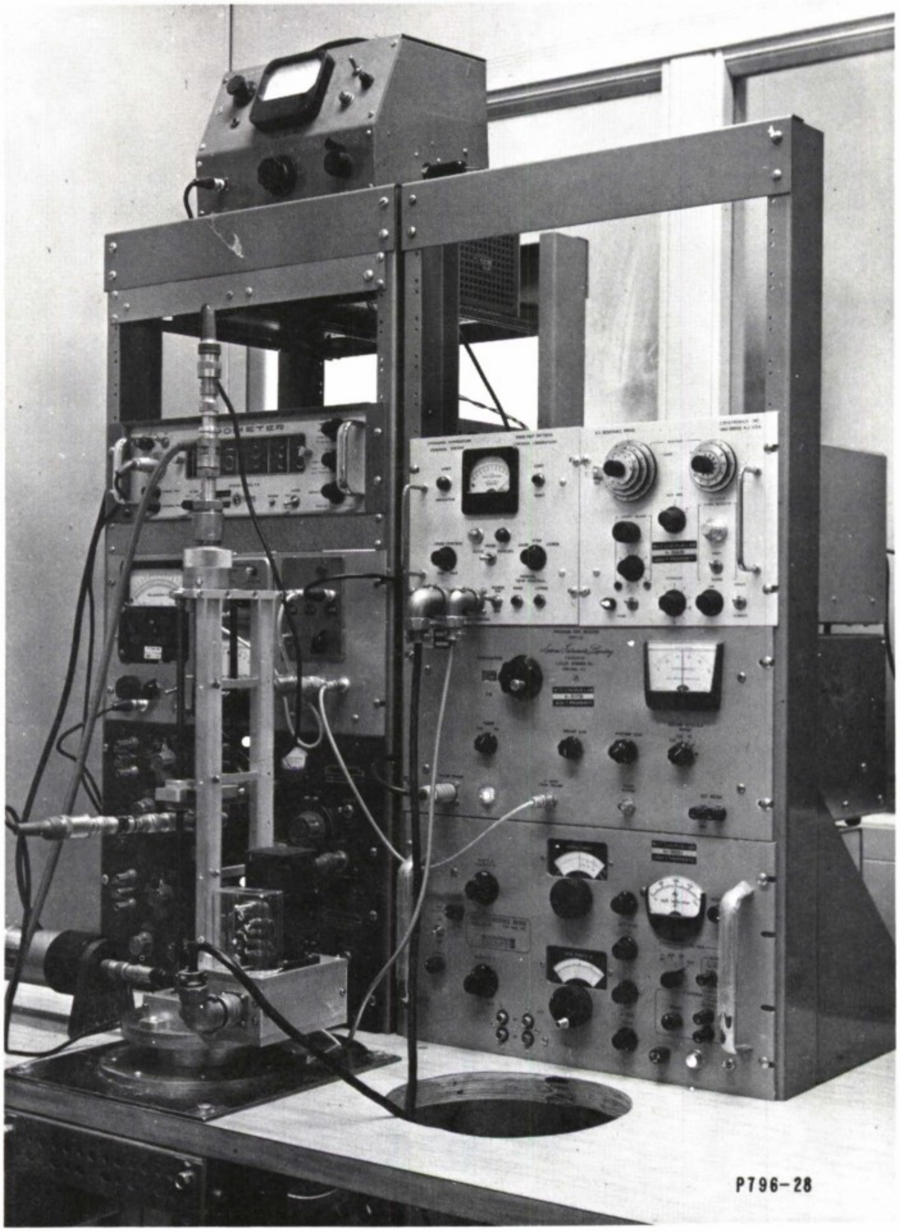

Fig. 11 The complete test setup for measuring varactor properties at cryogenic temperatures.

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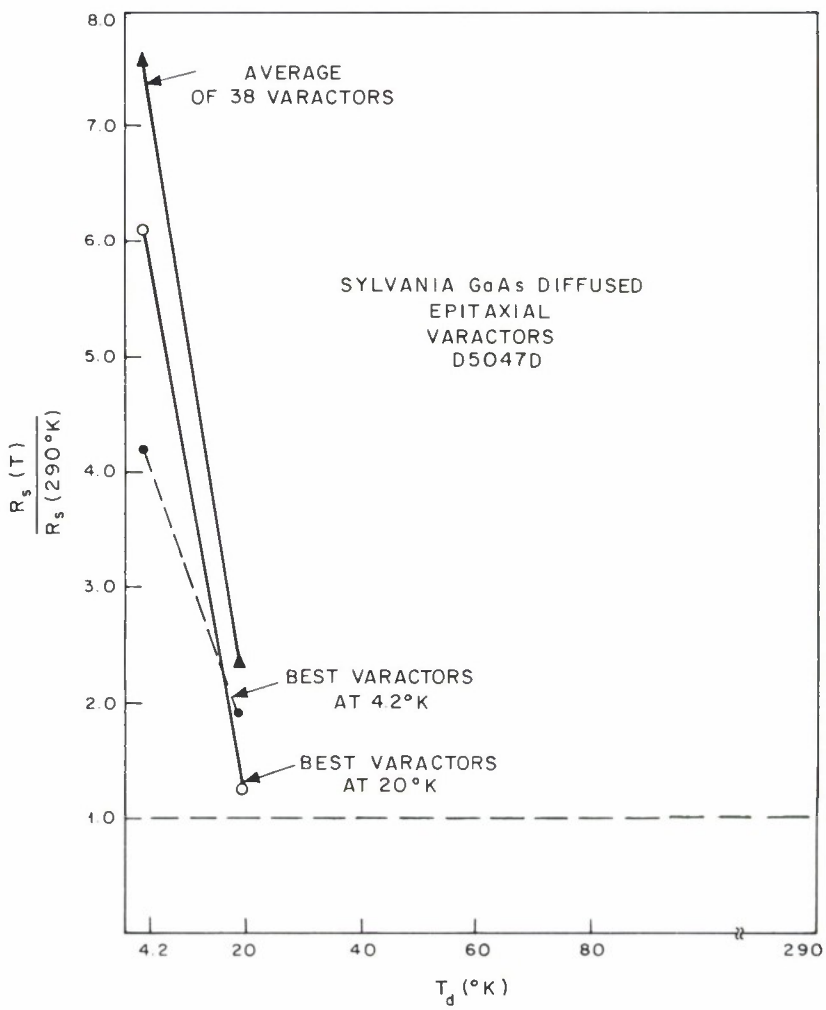

Fig. 12 $\frac{R_s(T^oK)}{R_s(290^oK)}$ versus T for Sylvania D5047 diffused epitaxial GaAs varactors.

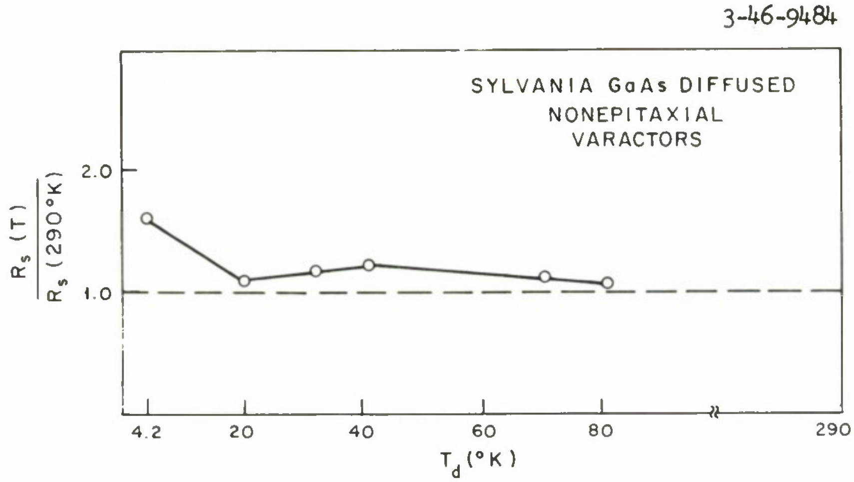

Fig. 13 $\frac{R_s(T^oK)}{R_s(290^oK)}$ versus T for Sylvania D5047 diffused nonepitaxial GaAs varactors.

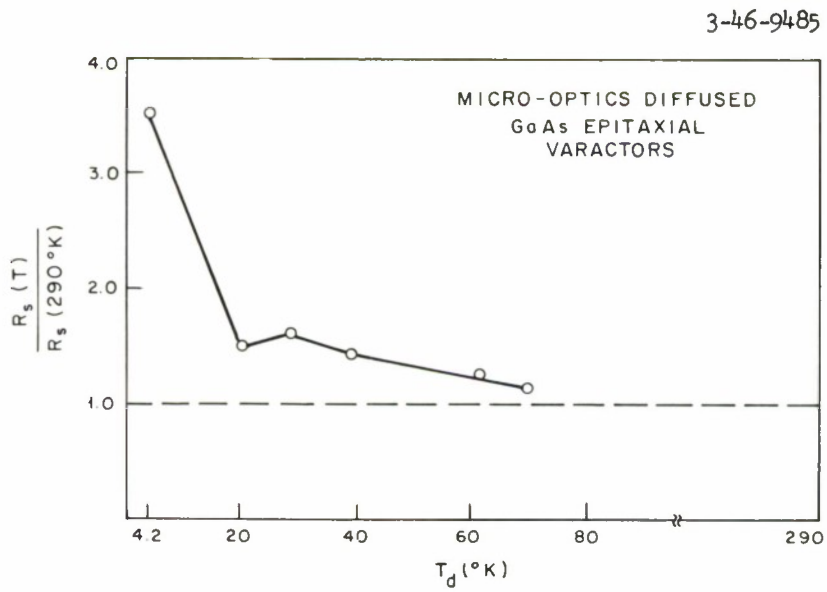

Fig. 14 $\frac{R_s(T^oK)}{R_s(290^oK)}$ versus T for Micro Optics diffused epitaxial GaAs varactors.

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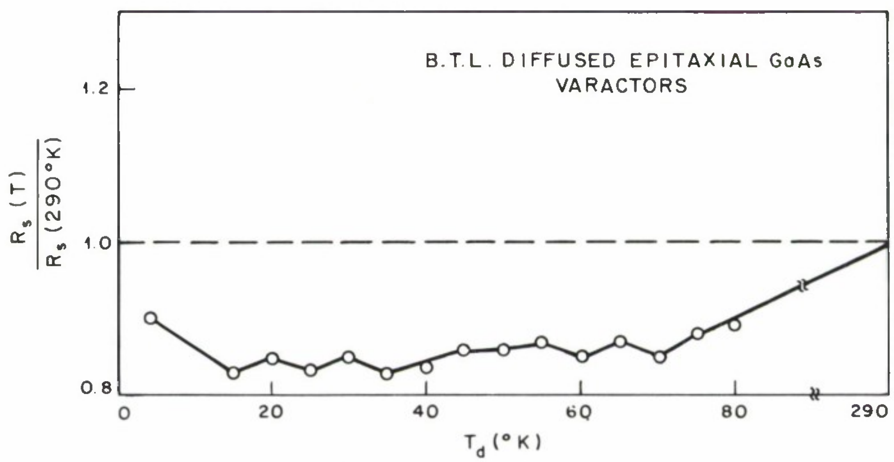

Fig. 15 $\frac{R_s(T^oK)}{R_s(290^oK)}$ versus T for Bell Telephone Laboratory diffused epitaxial GaAs varactors.

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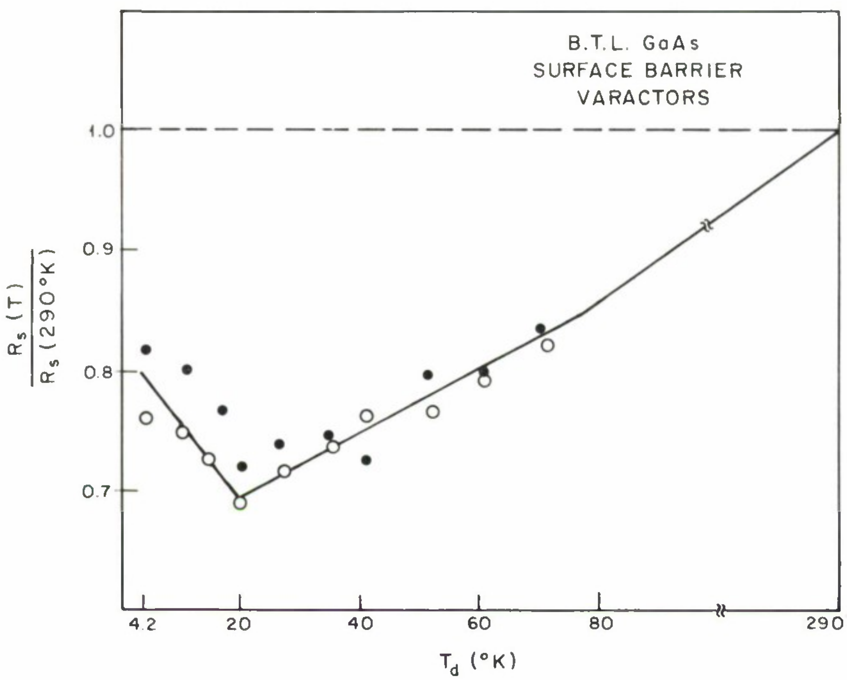

Fig. 16 $\frac{R_s(T^oK)}{R_s(290^oK)}$ versus T^oK for a Schottky barrier varactor.

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13. ABSTRACT

A discussion of the properties needed to obtain high-quality varactors is presented. Test data are also presented on state-of-the-art varactors as they are cooled from room temperature (290°K) to liquid helium temperature (4.2°K).

14. KEY WORDS

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